APPROACHES TO MINE SUBSIDENCE IN FOUR U.S. COMMUNITIES

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ABSTRACT

Millions of acres of land in the United States have been mined for coal and other mineral resources. Mine subsidence is a widespread problem in many of these areas. Coal mine subsidence has been documented in 31 states and on lands belonging to six Indian tribes. The authors propound the question — how are communities addressing mine subsidence problems? A response was sought from four communities with long histories of subsidence and significantly different State resources available for abating such problems. It was found that communities are seemingly most willing to accept hazard abatement by the State Abandoned Mine Land (AML) Program as a viable solution in addressing mine related problems. They also appear amenable to subsidence prevention via backfilling of mine voids provided State funds are available. One community encourages new construction to be subsidence resistant but does not mandate requirements. Land-use planning that includes zoning, enhanced building design, and backfilling select areas are favored by the authors but considered an anathema to city officials. All four communities encourage or require developers to review mine maps prior to designing new construction but none require avoidance of undermined areas. It is believed that, one day, communities will choose a more aggressive approach in minimizing the potential impacts associated with subsidence. When this choice is made, they will need the information we seek as AML Program managers to fully realize the scope of mine problems and have the tools necessary to take action. We suggest that State AML Programs can contribute significantly to minimizing subsidence impacts by collecting and preserving mine maps and by making them readily available so that the public and community officials can use them for making wise land use decisions. We present other ideas for State AML Program managers that may contribute to the implementation of wise land use practices by local communities.

INTRODUCTION

In the United States today, there are millions of acres of land that have been underground mined for coal and other minerals. Many of these lands are located within an easy commute of our modern cities and towns, and these communities are expanding toward and, in many cases, over undermined areas. As a result, residents and business owners are being exposed to dangerous mine-related problems. Such problems include mine subsidence, explosive and poisonous mine gasses, shaft openings, and mine fires. In addition to these hazards, there are unnecessary economic losses in terms of property damage, insurance loss, and disruption of commercial activity.

When the United States Congress passed the Surface Mining Control and Reclamation Act (SMCRA) in 1977, they authorized collection of funds to protect the public from past coal mining activity. In addition, SMCRA establishes Federal and State Programs to identify and abate mine-related problems. Congress identified priorities for expenditure of the funds and expressly identifies as the top priority for this legislation "the protection of public health, safety, general welfare, and property from extreme danger of adverse effects of coal mining practices." This is known as "Priority One" of the Abandoned Mine Land (AML) Reclamation Fund. Congress went on to state in Section 409 of SMCRA that voids and open and abandoned tunnels, shafts and entryways resulting from any previous mining operation were a hazard to public health, or safety. This extended the reach of SMCRA to non coal mines which met certain conditions.

During the program's 25 years of existence, much has been learned about mining and mine-related problems. Many of the problems have been remediated by State and Federal AML Reclamation Programs. The upcoming sunset of the AML fee collection authority in 2004 begs the question, "if the AML Reclamation Program were to end today, would there continue to be significant and life-threatening problems associated with old mines?" The answer to this question is an unequivocal "yes". Increased development over abandoned mines will expose more structures and people to subsidence risks. Many of these problems will not surface for 5, or 20 or even 50 years. But when they do, they will have devastating consequences for the residents and businesses affected.

While the State AML Programs have done an excellent job of abating subsidence problems when they occur, they have little authority or ability to minimize risks of future subsidence, The responsibility to protect the public from these risks lies with local governments, which have the ability to implement zoning and building code restrictions that can reduce the hazard exposure. The authors have found that local governments are avoiding the issue. This paper will examine four typical communities whose response is considered representative of virtually all communities facing mining problems. We will speculate on why this is happening and provide suggestions of how State Abandoned Mine Land Reclamation Programs can help these authorities to act proactively and in a responsible manner. By doing so, the State Reclamation Programs can truly fulfill the intent of Congress and discharge their duties in protecting the public from all AML problems.

MINE SUBSIDENCE AND COMMUNITIES

Mine subsidence is the collapse of the ground surface over areas where coal or mineral ores were removed. Subsidence causes ground surface deformation resulting in a range of problems from deep holes with vertical sides that pose physical threats to people, to more subtle forms of subsidence characterized by sagging of the ground surface producing more damage, over larger areas, affecting nearly all man made structures. Frequently, water and gas lines are ruptured; roads, bridges and homes are damaged; and commerce is disrupted. Subsidence in developed areas is often classified a Priority 1 Problem under SMCRA.

Subsidence is an onerous problem. The underground mine lays dormant and forgotten until, one day, failure within the mine has progressed upward far enough that it reaches the ground surface. Subsidence damages, therefore, tend to be sudden and unexpected. History has demonstrated that nearly any undermined area regardless of depth, where significant volumes of coal or mineral ore were extracted, is susceptible to subsidence. As an example, coal mines in Illinois over 900 feet deep have subsided and continue to cause damages to modern improvements.

Today, we find that cities, towns, and individual homes and businesses are spreading rapidly across the lands underlain by abandoned mines. In Illinois, as in other areas of the Midwestern United States where the authors are most familiar, economic loss associated with mine subsidence affecting homes and businesses seems to be on the increase[1]. The spread of community development over undermined lands is exposing the public to increasing safety and economic risks and costing communities millions in unnecessary repairs to public facilities and infrastructure.

IS SUBSIDENCE A WIDESPREAD PROBLEM IN THE US?

Subsidence over coal mines is documented in 31 states and on the lands of 6 Indian Tribes. While the extent of subsidence over non-coal mines is largely uncharted, we know that non-coal minerals have been mined by underground methods in nearly every state and that subsidence is associated with many of these mines as well. One of the most extreme cases of subsidence in Illinois formed over a mine that extracted the mineral, galena. In the Midwest, subsidence in towns and cities has been documented since the 1800's.

Preliminary findings from an ongoing study in Illinois (Gibson, Smith, Schottel, and Pearson) may be illustrative of the larger picture of the relationship between underground mines and development in cities across the country. The data are presented herein for discussion purposes only and formal findings will be published when the study is complete.

> The Illinois Department of Natural Resources is producing a working set of data layers for a geographic information system that combines detailed mine maps with surface maps for the entire state. Cursory inspection of maps for one city reveals that large areas of the city are undermined and that it is continuing to grow outward onto additional undermined areas. The continued urban development over the mines with apparent disregard for past mining is disconcerting. For example, nearly 86 large commercial and public buildings and 245 residential and multi-family dwellings are located over a single mine in this city. This particular mine underlies approximately 722 acres of land of which 441 acres (61%) has surface development. Given its location, continued commercial development is expected.
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> Recently, another layer was added to the map showing 348 known and/or suspected mine subsidence features for this particular city. This information is compiled from many sources and is updated with

new information. It includes data on subsidence events having formed during the past 80 years (at least). One source, John C. Quade, representing the Federal Land Bank of St. Louis, identified 103 subsidence problems having formed prior to 1934. The total area affected by the 348 subsidence features has been estimated to represent 3% of the 36,535 acres of land mined in the study area.

It would appear that, with such a long history of public exposure to subsidence across the nation, significant work might have been done by government agencies to reduce the risks to public safety and investment. Unfortunately, this does not appear to be the case.

WHAT CAN BE DONE TO PREVENT OR MINIMIZE SUBSIDENCE DAMAGE?

There are several actions that government agencies may take to prevent or minimize public safety risks and lessen damage due to subsidence:

- Fill mine voids with non-compressible materials.
- Encourage appropriate land use in subsidence prone areas through zoning.
- Encourage enhanced building and engineering codes to make structures safer, more durable and to facilitate repair.
- Take special precautions when constructing public works projects such as roads, bridges, sewers and public buildings.
- Provide education, map resources, and technical guidelines to the public and to developers.

If mine voids can be completely filled with a durable, non-compressible material, the potential for subsidence can be completely eliminated. Backfilling is perhaps most effective and cost efficient when used to protect a costly surface development covering a small surface area. Backfilling is, however, much more difficult to accomplish than one is often lead to believe. It is extremely costly to backfill entire mines regardless of the method used. It is more expensive and difficult in developed areas, with the added risk of perhaps inducing subsidence in the process. Backfilling has been used extensively on an emergency basis across the US to reduce the extent of subsidence damage to individual structures after ground movement has started. However, large area backfilling projects have only been undertaken in a few cities in the United States due to the high cost and risks associated, most notably in Rock Springs, Wyoming. It has been demonstrated that few state governments and even fewer local governments have the financial resources for such costly projects. Wyoming, with the immense coal production of the Powder River Basin, has used some AML money to proactively limit subsidence potential in Rock Springs. However, The cost associated with large-area backfilling projects prohibits their use in most situations. This leaves the remainder of the options stated above for use by local and State governments.

THE ROLES OF LOCAL AND STATE GOVERNMENT AGENCIES

In the United States, decisions regarding land use, development, and most building standards are generally made at the local level. Common building code manuals, such as BOCA, UBC, and the proposed IBC do not address the impacts of mining. State and Federal government entities tend to respect local government land use decisions. Some governmental entities, most notably the Abandoned Mine Land programs, have no authority to restrict building and land use development.

Land use and development decisions are based on seeking a balance between competing spheres of influence, most notably, technical concerns, public safety, economic well being, and special interest groups. The latter two exert tremendous pressure at the local level. There are several actions that local governments may take to prevent or minimize risks of subsidence in undermined areas:

Implement restrictive zoning in subsidence risk areas.
Implement building codes or engineering standards for subsidence risk areas.
Take special precautions when constructing public works projects such as roads, bridges, dams, sewers, and public buildings.
Provide education, map resources and technical guidelines to the public.

WHAT ARE LOCAL GOVERNMENTS DOING?

In 2001, the authors sought to determine what local governments were doing to lessen the potential risks associated with future subsidence. We chose four communities with long histories of subsidence and significantly different State resources available for responding to subsidence problems. These communities are:

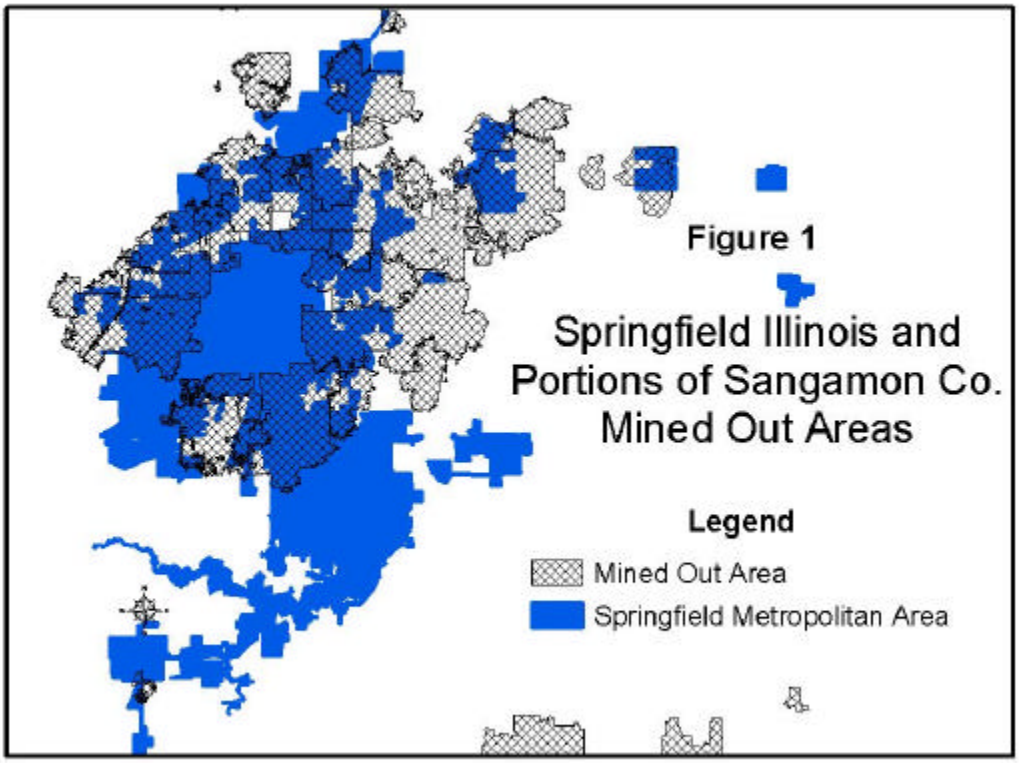
Springfield, Illinois
O'Fallon, Illinois
Pittsburg, Kansas
Rock Springs, Wyoming

In order to determine what actions were being taken by local authorities, the authors interviewed city engineers and/or Planning and Zoning Department managers in each community and asked the following questions:

- Does your community have and enforce special zoning restrictions for subsidence prone areas?
- Does your community have specific building codes or engineering standards for development over subsidence prone areas?
- Is subsidence insurance available?
- Does the city encourage developers to look at mine maps or consult the State AML office prior to designing new buildings and improvements?
- Does the city avoid undermined areas or use special engineering standards when locating new facilities or designing new buildings and infrastructure?

The results were a bit surprising. Following is a summary of the findings for each community.

Springfield, Illinois



Underground mines occur under a significant portion of the Springfield Metropolitan Area (Figure 1)[2]. Sag subsidence is occurring on a regular basis in a number of areas including recently developed residential subdivisions and retail areas. Illinois has a subsidence insurance program and a state AML Emergency Program. City officials expressed concern about potential subsidence impacts on both existing structures and future development.

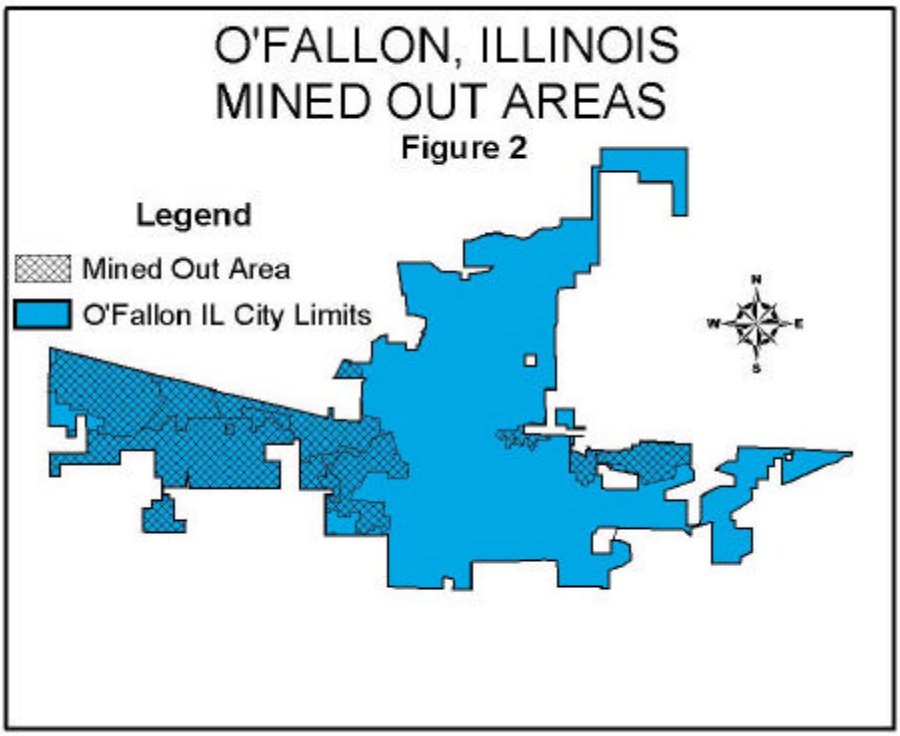
In spite of these issues and concerns, Springfield city officials told the authors that in subsidence-prone areas:

They do not impose zoning restrictions.
They do not advocate special building codes or engineering standards.
They allow engineers and developers to review their maps of mining and subsidence activity.
They do not, in general practice, use different engineering practices for public works.

This development policy results in continued growth over areas with significant subsidence potential. Buildings are being constructed without regard to mining. There is no

consideration in taking advantage of variance within mining geometry in order to select potentially stable areas for siting important structures. Any special actions that are taken to strengthen or protect new construction are entirely voluntary and up to the design engineer.

O'Fallon Illinois



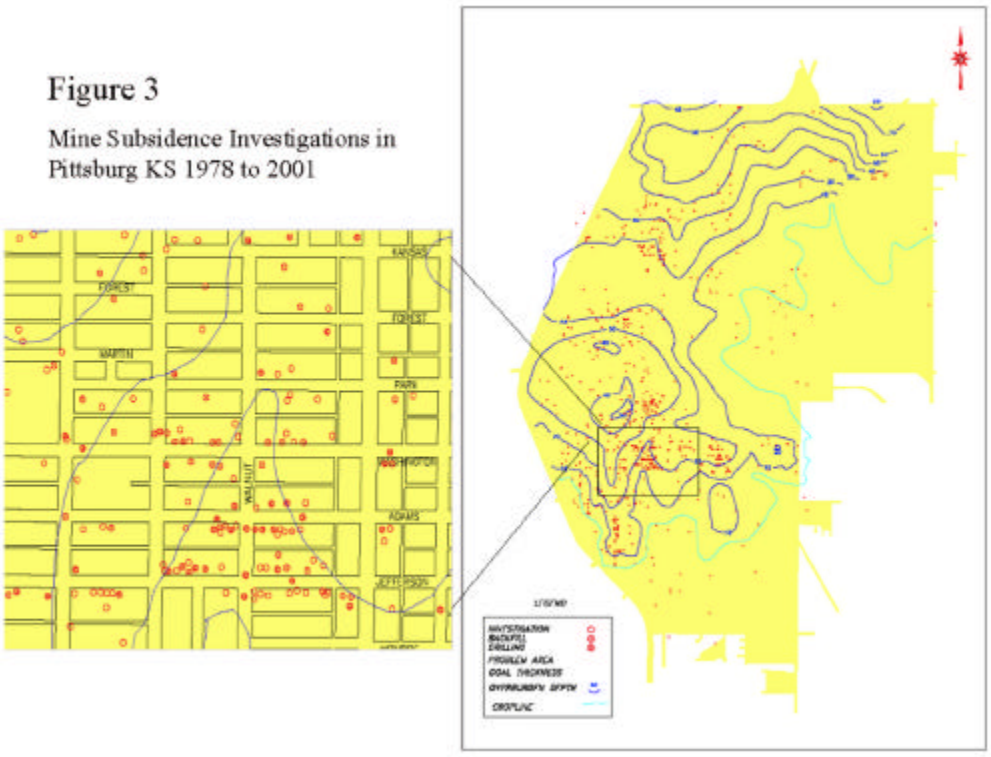
O'Fallon is another Illinois city where a significant portion of the community is undermined for coal (Figure 2)[3]. The city is land locked by other communities and cannot expand its borders. Therefore, O'Fallon is limited to developing the lands it already has within the city limits.

Interviews with O'Fallon community officials[4] yielded similar results in that there are no zoning restrictions, special building codes, or engineering standards specific to subsidence. However, we did find differences. The city requires developers to consult with the State AML office regarding the location of underground mines, although it does not specify what the developer must do with the results of the consultation. O'Fallon is also in the process of redesigning a main forced sewer line that was recently damaged by subsidence. The new sewer is being built to resist future damages from subsidence in the area.

Pittsburg Kansas

Figure 3

Mine Subsidence Investigations in Pittsburg KS 1978 to 2001



Pittsburg Kansas is a small city in southeast Kansas with a population of just over 19,000 residents whose mining history dates to the mid-1800's. Approximately 2/3 of the city is located above shallow coal mines that range in depth from less than 20 feet to about 50 feet. Figure 3[5] shows the location of subsidence investigations within city limits over the past 23 years. The State of Kansas AML Emergency Program responds to an average of 40 mine subsidence emergencies per year. However, because underground mines only affect a small number of towns in Kansas, there is not sufficient support for a state-wide subsidence insurance program. Pittsburg officials responded to the authors questions as follows[6]:

They do not impose zoning restrictions.
They do not advocate special building codes or engineering standards.
They encourages developers to look at mine maps and consult the State AML Office prior to developing design plans.
They do not design public works projects to resist subsidence unless undertaking repair for subsidence damage.
They allow the public to view mined-area maps, but maps for many areas are not available.

Rock Springs, Wyoming

A large percentage of Rock Springs has been undermined for coal. The Wyoming AML Program has considerable monetary resources because of its current coal mining production allowing it to devote considerable funding to subsidence prevention. Wyoming

has backfilled the mine workings under most developed areas of the city using various mixtures of sand and grout. Undeveloped areas were not backfilled. Subsidence insurance is available in Rock Springs, and many lenders require it as a condition of loan approval.

Interviews with city officials[7] revealed the following conditions:

They do not impose zoning restrictions.

- Proposed developments over non grouted areas must have foundations engineered to resist subsidence.
- Lenders require subsidence insurance.
- Public works projects are not designed to resist subsidence unless a repair for subsidence damage is being undertaken. High risk areas are avoided when possible.
- The city and state allow the public to view mined-area maps.

SURVEY CONCLUSIONS

In spite of ongoing subsidence problems, none of the four local governments chose to impose subsidence specific zoning restrictions. Three of the four communities do not impose subsidence resistant engineering standards or building codes. Rock Springs requires structures in non-backfilled areas to be designed to resist subsidence damage, but does not mandate specific criteria. None of the four communities routinely design public works in undermined areas to resist subsidence damages although several have recently begun designing repair and replacement projects for roads and sewers damaged by subsidence to be more resistant to future damage. Rock Springs officials stated that they were trying to avoid building public works over non-backfilled mines when other options are available.

The one positive, common condition among the four communities is that they all encourage engineers and developers to review available underground mine maps prior to project design. Unfortunately, the cities do not direct the builders to take any specific actions once the maps are viewed. In many cases, mine maps are unavailable or are poorly referenced to local coordinate systems and street maps. Based on the survey results and firsthand observation, the authors conclude that local governments are not likely to alter development based on subsidence potential or restrict building design in the near future.

WHY ARE LOCAL GOVERNMENTS HESITANT TO IMPLEMENT SPECIAL REQUIREMENTS?

From our perspective, there seems to be an incongruity between the level and amount of damage to surface development and public awareness and response. Perhaps it is because each subsidence event is somewhat isolated, and each event impacts relatively few people. In contrast, natural disasters such as earthquakes, floods, and major storms that affect a great many people in a short period of time focus public awareness. Perhaps another reason is that there is very little hard data documenting the impacts of subsidence

for a community and scant information at the regional and national level. Circumstantial evidence suggests that subsidence is pervasive but not sufficiently cataclysmic to draw significant public and political attention. What is this circumstantial evidence? In Illinois the following historical facts are suggestive:

- 1809 William Boone shipped coal from Illinois to New Orleans.[8]
- 1833, mines in St. Clair County, Illinois ship 6,000 tons of coal to St. Louis, Missouri. [9]
- 1880, in *Wilms v. Jess*, the Illinois Supreme Court handed down its first decision on coal mine subsidence. [10]
- 1916, the ISGS publishes "Surface Subsidence In Illinois"
- 1926, Mines and Minerals is established.
- 1975, Abandoned Mined Lands program is established to address environmental concerns.[11]
- 1979, Subsidence Insurance Coverage is mandated.
- 1984, Illinois Emergency Program is established.

This pattern of mineral extraction, followed by legal contests, regional studies, and creation of institutions and policies, was also carried out in similar fashion in other states and on a national level. One might conclude from the discussion thus far that government institutions are proceeding very slowly in addressing the problems associated with mining. Some will argue that additional governmental response is not necessary. However, examination of the list suggests two things. First, there is a continuing conflict between mining and surface land use. Second, the impact on urban development is increasing even though the number of subsidence events may be constant. Preliminary and limited data in Illinois suggests that subsidence is more common than previously believed and that large mined areas apparently have yet to subside. Discussions with community officials suggest that there are insufficient economic incentives to merit limiting development in undermined areas.

ILLINOIS' ATTEMPTS TO REDUCE SUBSIDENCE RISKS

In Illinois, local government has, for the most part, left the issue of subsidence to the State AML Program and to individual residents who are directly affected. State government has taken the lead in protecting the citizens in several important areas. Examples of State initiatives include providing the public information to avoid and cope with the problems associated with past mining.

Maps - AML Program staff feel that the best way to limit mine-related problems, such as subsidence, is to avoid mined areas all together or, if possible, to prevent the negative effects associated with mining. To do so, it is necessary to know where the mines are located relative to ground surface features and to be knowledgeable about the kinds of problems that can be expected. Such information has to be made widely known, readily available, and easily understood. The most common means is through the use of maps.

Illinois is trying to help the public avoid the effects of mined areas by making mine maps readily available. This is a continuing process.

Several kinds of mine maps have been developed for varying reasons, but most relate the location of the extracted mineral with respect to ground surface features. Illinois is attempting to compile all these maps into a "Computerized Mine Information Map" and make it widely available to the Public in an appropriate manner. Until then, the most widely available mine maps in Illinois are its mined-out area maps (MOA's). The current generation of MOA's are color maps made at a 1:24,000 scale and overlain onto USGS topographic maps. Each map is complete with a companion booklet that includes mine histories detailing production years, name changes, and other pertinent information. Such maps are available for purchase as "hard copy" or can be downloaded off the internet at no charge in 'PDF' or in GIS format.

Blue-line copies of the mine workings maps that exist for nearly 2000 mines have been stored in State Archives and are available for inspection. Age and continued handling have caused severe damage to the maps. In an effort to protect these maps for historical purposes and to make them more available, the maps were photographed and stored on microfiche. Microfiche copies were made available to the Public on demand at no charge. Technological advancements during the 1980's lead to the practice of scanning the images stored on microfiche and then saving the electronic image in digital format on compact discs. Apparently, this practice is also being carried out on a national level. The authors acknowledge that there are many good reasons supporting this decision including media durability, convenient storage, increased access and dissemination of information, and reasonable cost. However, the authors wish to make it clear that this practice should be employed only with the utmost care for quality control in order to insure image integrity. Furthermore, there can be significant degradation in the image quality that can mislead map readers into believing an area is not undermined. We advocate high resolution scanning of the earliest generation mine map available and saving this image to long-term storage media. This task is being undertaken in Illinois as a means to store each mine map for historic purposes and to make the images widely available on the internet. A complete discussion on this topic will be presented in a forthcoming publication.

The department has identified four critical needs in preserving mine map information and making it more readily available for future generations.

1) **Preserve and protect mine map information**. Create high quality copies of each mine map. Each mine map is to be scanned and stored in digital form. The resulting digital image will be the visual equivalent of the original map.

2) **Archival storage and retrieval of individual digital maps**. The scanned mine maps are to be stored onto CD-R media. Each map is to be uniquely identified so that individual mine images can be conveniently accessed from its stored location and displayed. Further, each mine map is to be cross-referenced with the Department's mine index number system.

3) **Reference mine map to a surface coordinate sytem**. Each map sheet is to be located with respect to surface features to within the same relative accuracy of the mine map and

the reference map (typically a USGS 7 - minute Topographic Quadrangle). The rectification process will employ the transformation method that minimizes total image distortion. In Illinois, map sheets will be referenced to the Universal Transverse Mercator map projection (North American Datum 27).

4) **Enhance Mine Map Availability**. The Public will have the option of ordering hard copy maps or viewing and printing maps using internet map server technology.

Model Ordinances - The Illinois AML program subcontracted with the Southwestern Metropolitan Planning Commission (SWMPC) to develop a resource document for cities and communities located in or near mined areas. This resource document contains educational material concerning mining and mine-related problems, a discussion on how to evaluate development risk and site public structures, a list of contacts that provide help should mine problems develop within the community and finally, a model ordinance the community can use to plan future development that minimizes the negative effects associated with mining. This resource document " Mine Subsidence: A Guidebook for Local Officials" was written in 1983 and was sent to all local governments in mined areas in Illinois. While there has not been a follow-up study to verify whether a community has attempted to follow the Model Ordinance, the authors are unaware of any communities patterning new development after it. City officials appear to believe that such attempts will place their community at an economic disadvantage, and that businesses will choose to locate in communities with lesser restrictions given equivalent markets.

WHAT CAN STATE AML PROGRAMS DO TO LEAD THE WAY?

The AML program is a sunset program. Our legacy should be that we as program managers and policy makers develop the data base necessary to assess the probability of subsidence risk and make resources available for people to make educated decisions before such information is lost. What steps should we be taking?

Collect the maps before they are gone - First, we must be making significant efforts to identify and collect all existing mine maps. These resources are being lost at a rapid rate as mining companies are consolidated and as older miners are passing away, leaving stores of maps and records to be thrown out as trash by ill-informed employees and heirs.

Capture Map Data using GIS - We must be creating accurate geographic information systems that capture, archive, and display mine location and other valuable information that will help provide communities, businesses, and individuals the tools necessary to address problems associated with mined lands. In developing these geographic information systems, we need to document the current condition of past and existing mines. In addition, we need to document as much as possible the location, size and date of each subsidence event, and the typical conditions as well as any unusual conditions of the mine. For instance, there are mines in Illinois where unusually large caverns are created underground to facilitate coal separation and shipping. Such large caverns can cause atypical and extreme subsidence at ground surface. Other mine information such as

fires, back stowing, and backfilling also influence future mine stability and need to be documented. All such information needs to be placed on the mine map and saved for future reference.

Make data available to the public - Creating accurate maps and making them available to the public is the next step. Information is only useful to the public if it is available and understandable. A more innovative method for distributing the information to the public is the use of an internet map server to provide the public and community leaders the ability to create their own maps from their computers.

RECOMMENDATIONS ON ARCHIVING, GIS AND MAPPING

The authors believe it is important for each AML program to make digital copies of all mine maps for future use. One should assume that access to the original hard copy map will not be available for copying ever again. Therefore, extreme diligence in quality control is critical, and the digital copy should be the equivalent of the original map. Do not limit image quality based on file size concerns. Care should be exercised in choosing a scanner that keeps image distortion to an absolute minimum and is sized to make 1:1 ratio in copying. Finally, when choosing a file format for digital storage, consider one that can be used by many imaging programs and is not proprietary. Illinois is storing the digital information as TIFF files.

CONCLUSION

The lessons learned from 25 years of AML experience need to be applied towards efforts that prevent future damage and injury from mine subsidence. Collection, preservation, and digital mapping of underground mine information is critical to smart development and land use planning. Development and community planning, with an eye to subsidence damage minimization, can prevent underground mine features from becoming priority 1 and 2 AML problems. By making this information available to community leaders and informing the public of the importance of such knowledge, we will go a long way to meeting the first priority of the AML Reclamation Fund “protection of public health, safety, general welfare and property from extreme danger of adverse effects of past coal mining practices”. While we, as state and Federal AML professionals, cannot take direct actions to regulate development of undermined lands, we can collect, preserve, and provide to the public the information that will be essential in making informed land use decisions in the future. The AML Programs are the only organizations with the direct authority to capture and preserve this valuable information and make it available to this and future generations.

This kind of information becomes vital should cities chose to plan their development over mined areas. Without question there are structures, perhaps many, being built over mined areas without adequate protection. It seems a matter of time before a massive failure with serious consequence occurs causing unprecedented damage and loss of life. The resulting litigation will cause change in public policy.

Will we have done our part to preserve the information necessary for communities to make wise land use decisions?

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